



BUILDING COMMISSIONING GUIDE

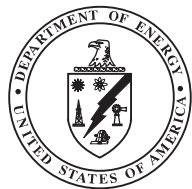
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GLOSSARY

Building Systems - The architectural, mechanical, electrical, and control systems along with their respective subsystems, equipment, and components.

Building Commissioning - In the broadest sense, a process for achieving, verifying, and documenting that the performance of a building and its various systems meet design intent and the owner and occupants' operational needs. The process ideally extends through all phases of a project, from concept to occupancy and operation.

Commissioning Authority - The qualified person, company or agency that plans, coordinates, and oversees the entire commissioning process. The Commissioning Authority may also be known as the Commissioning Agent.

Commissioning Final Report - The document prepared during the acceptance phase of the commissioning process after all functional performance tests are completed. It includes the executive summary, building description, and the completed commissioning plan, including all documentation generated during the process along with the completed commissioning test plans.

Commissioning Plan - The document prepared for each project that describes all aspects of the commissioning process including schedules, responsibilities, documentation requirements, and functional performance test requirements. The level of detail depends on the scope of commissioning specified.

Commissioning Test Plan - The document that details the pre-functional performance test, functional performance test, and the necessary information for carrying out the testing process for each system, piece of equipment, or energy efficiency measure. The test plans are included as an appendix to the final report.

Construction Manager - An organization who's role is to manage the construction team and various contractors to build and test the building systems for the project. The Construction Manager also works with the Commissioning Authority to identify and correct any deficiencies.

Design Document - The record which details the design intent.

Design Intent - Design intent is a detailed technical description of the ideas, concepts, and criteria defined by the building owner to be important, and should include facility functional and environmental needs. The design intent is developed by the design A/E from descriptions provided by the building owner.

Design Professionals - The architects, engineers, or other parties responsible for the design and preparation of documents for the various building systems.

Energy Efficiency Measure - Any equipment, system, or control strategy installed in a building for the purpose of reducing energy consumption and enhancing building performance. An energy efficiency measure may also be called an energy conservation measure.

Functional Performance Test - The full range of checks and tests carried out to determine whether all components, subsystems, systems, and interfaces between systems function in accordance with the contract documents. In this context, “function” includes all modes and sequences of control operation, all interlocks, and conditional control responses and all specified responses during design day and emergency conditions.

Pre-Functional Performance Test - A series of tests for specified equipment or systems, which determine that the systems are installed correctly, start up, and are prepared for the functional performance tests. Often these tests are in a checklist format. The pre-functional test checklists may be completed as part of the normal contractor start-up test.

Recommissioning - The periodic retesting of building systems using the original functional performance tests to ensure the equipment continues to operate as designed.

Seasonal Performance Tests - The full range of test procedures carried out to determine if all components, equipment, systems and interfaces between systems function according to design intent during heating or cooling design days. When it is not practical to perform the test during an actual design day, these conditions may be simulated.

System Commissioning - In a narrower sense, the act of statically and dynamically testing the operation of equipment and building systems to ensure they operate as designed and can satisfactorily meet the needs of the building throughout the entire range of operating conditions.

Chapter 1

BUILDING COMMISSIONING FOR THE FUTURE

Background

Executive Order 12902, *Energy Efficiency and Water Conservation at Federal Facilities*, signed by President Clinton on March 8, 1994, requires in Section 501(i) that the Department of Energy and the General Services Administration develop a model building commissioning program. This *Building Commissioning Guide* addresses the relatively new field of building commissioning, and outlines a broad model building commissioning program for Federal agencies.

Historically, the term “commissioning” has referred to the process by which the heating, ventilation and air conditioning (HVAC) system of a building was tested and balanced according to established standards prior to acceptance by the building owner. For the most part, the HVAC commissioning did not include systems, such as water, lighting, and control, which did not directly affect the performance of the HVAC system. In contrast, “building commissioning” is a process for achieving, verifying and documenting that the performance of a building and its systems meet the design intent and the owner and occupant needs. This guide takes this broad definition of building commissioning and applies it to buildings in the Federal sector to ensure that the new and renovated Federal buildings, and all the systems contained in them, operate specifically according to the energy efficiency and operational requirements in EPACT, and E.O. 12902.

At the request of many of the Federal agencies affected, the guide takes a broad approach and is intended to introduce the concept of building commissioning to Federal agencies by providing sufficient detail so that agencies can use it to develop their own building commissioning programs. This guide exceeds the minimum commissioning requirements outlined in E.O. 12902 section 306(a)(3) concerning agency requirements for commissioning to ensure energy efficiency. The approach to building commissioning in the guide is modeled on GSA’s experiences and business practices which have been applied in government building construction projects which meet both EPACT and E.O. 12902 requirements.

Good design, construction, and operational practices, which may not normally be considered building commissioning by some agencies, have also been included. Regardless of the structure of an individual agency's commissioning program, the results of a building commissioning program should achieve the same goals and include:

- A well-documented design intent,
- Tests that show that the building systems and the building as a whole functions as required by the owner, most specifically as required by the contract drawings and specifications, and
- Documentation and training provided for the building operators so that they can continue to operate the building as it was intended to function.

Benefits of Building Commissioning

The traditional method of building design and turnover did not ensure a building would meet the performance needs of the agency and building occupants. In addition, the needs of facility maintenance personnel were not addressed, preventing them from maintaining the building's performance at maximum efficiency. Figure 1-1 illustrates several other reasons why a building commissioning program is necessary.

Building owners, contractors, and vendors are becoming increasingly aware of the many benefits to be derived from a better managed, quality design and construction program produced by the commissioning process. In addition to meeting the requirements of EPACT and E.O. 12902, a properly commissioned building improves building functions and operations, including increased comfort, better air quality, and fewer O&M problems.

During construction, building commissioning provides the following benefits:

- Identifies and meets owner requirements in accordance with the design intent;
- Helps meet cost objectives by reducing costly change orders due to errors and omissions;
- Reduces contractor callbacks, allowing contractor to focus efforts on other projects and obtain payments on schedule; and
- Reduces construction time due to fewer conflicts and change orders.

Figure 1-1
Traditional Factors Supporting the Need
for a Building Commissioning Program

- ✓ Unclear Design Intent
- ✓ Complex Building Systems
- ✓ Increased Specialization Without Integration
- ✓ Unclear Standards and Criteria for Gauging System Performance
- ✓ Lack of Functional Performance Testing
- ✓ Conflicts Between Specifications and Applicable Codes
- ✓ Inadequate System Documentation
- ✓ Maintainability and Accessibility Problems
- ✓ Inadequate Provision for Maintenance
- ✓ Inadequate O&M Manuals
- ✓ Inadequate Training of O&M Staff
- ✓ Numerous Change Orders and Cost Overruns

During occupancy, building commissioning provides the following benefits:

- Verifies the facility meets or exceeds minimum energy efficiency standards;
- Ensures facility operated in accordance with original design intent;
- Contributes to a comfortable, safe, and healthy environment by improving power quality, and indoor air quality;
- Helps provide adequately trained staff to operate and maintain the building according to the design intent;
- Reduces energy and operating costs by operating and maintaining systems at maximum efficiency;
- Reduces occupant complaints, minimizing costly service calls; and
- Provides documentation and training for operators and facility managers, ensuring continued savings and longer equipment life.

Economics of Commissioning

The implementation of a building commissioning process ensures that the building and building systems are operating as designed when the building is turned over to the agency. Building owners are finding that the cost of implementing a building commissioning process can be offset by the energy, water and

productivity savings achieved by the commissioned building. Recent studies indicate that on average the operating costs of a commissioned building range from eight to twenty percent below that of a non-commissioned building. The one-time investment in commissioning at the beginning of a project may result in reduced operating costs that will last the life of the building. In general, the cost of commissioning is less than the cost of NOT commissioning.

The cost of commissioning is dependent upon many factors including a building's size and complexity, and whether the project consists of building renovation, modernization, or new construction. Large, more complex buildings typically have higher commissioning costs than newer, smaller buildings. In general, the cost of commissioning a new building ranges from 0.5 to 1.5 percent of the total construction cost, as shown in Table 1-1. For an existing building, never before commissioned, the cost of commissioning can range from three to five percent of the total operating cost.

Table 1-1
Costs of Commissioning, New Construction

Commissioning Scope	Cost
Entire building (HVAC, Controls, Electrical, Mechanical) Commissioning	0.5-1.5% of total construction cost
HVAC and Automated Control System Commissioning	1.5-2.5% of mechanical system cost
Electrical Systems Commissioning	1.0-1.5% of electrical system cost
Energy Efficiency Measures Commissioning	\$0.23-0.28 per square foot
<i>Source: Portland Energy Conservation Incorporated</i>	

Chapter 2

OVERVIEW OF THE COMMISSIONING PROCESS

Commissioning is a systematic process for achieving, verifying, and documenting that the performance of the facility and its various systems meet the design intent and the functional and operational needs of the owners and occupants. The process extends through all phases of a project, from conceptualization to occupancy and operation, with numerous checks at each stage of the process to ensure that established procedures are followed. This process also includes training of the facility O&M personnel to ensure the continual efficient use of energy and water as originally designed. This approach to constructing a building—along with the necessary training of facility personnel—is not a substitute for a QA program, but will complement the QA process for building construction and the building construction industry.

The fundamental elements of a good building Commissioning Plan must:

- Create a procedure that will verify and provide documentation that the performance of the building and its individual systems meet the owner's requirements:
 - Tuned to meet actual occupancy needs
 - Meets comfort requirements during peak and partial loads
 - Energy efficiency is optimized within the designed operation of the building
 - Indoor air quality is kept in accordance with specified ASHRAE Standards
 - O&M documentation is complete
 - Operator training is completed
- Enhance communication by documenting all pertinent data and decisions throughout the project and clearly identifying:
 - Owner's needs and criteria
 - Design intent documents and forms
 - Decisions impacting design
 - Procedures for verification of system performance testing
 - All appropriate permits and fees
 - Construction inspection reports
 - Operational information
 - Maintenance criteria and procedures
 - Completed pre-functional performance tests

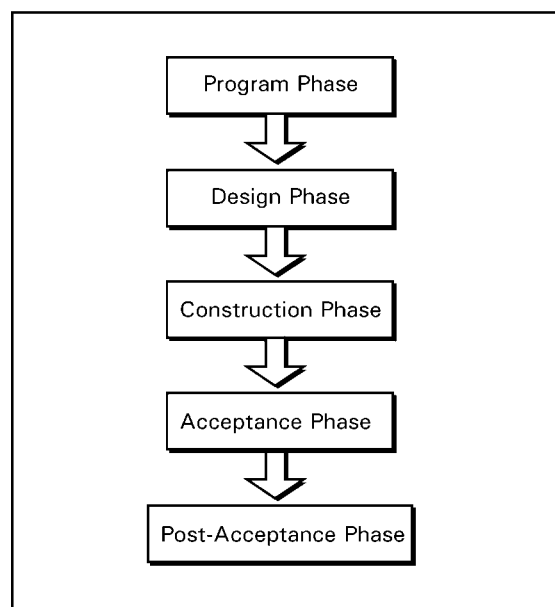
- Completed functional performance tests
- Test and balance reports
- Progress and status reports
- Scheduling conflicts and resolutions
- Confirm and report that building system performance meets design intent:
 - During peak and partial loads
 - During all seasons
 - Meets criteria for integrated system operation

However, if the original building design does not properly translate the Agency's requirements into the building, then regardless of the proper implementation of a commissioning process, the building will not achieve the operational, comfort, and efficiency requirements expected by the Agency.

The Building Commissioning Process, Overview

In general, any building commissioning process will fall into five phases, as shown in Figure 2-1, beginning with the Program Phase of a project and then following the typical phases of project delivery: Design, Construction, Acceptance, and Post-Acceptance. Depending on the project scope and size and whether it is major or minor construction, commissioning may not affect all phases.

Figure 2-1
The Five Phases of Building Commissioning



GSA's process for building project development falls into a 9 step approach which includes the following steps:

- Community planning and building evaluation for new construction and modern job projects,
- Enhanced prospectus development study,
- Approval and funding,
- Pre-design activity,
- Design, review, and approval,
- Pre-construction activity,
- Base construction,
- Buildout, and
- Verification of design intent.

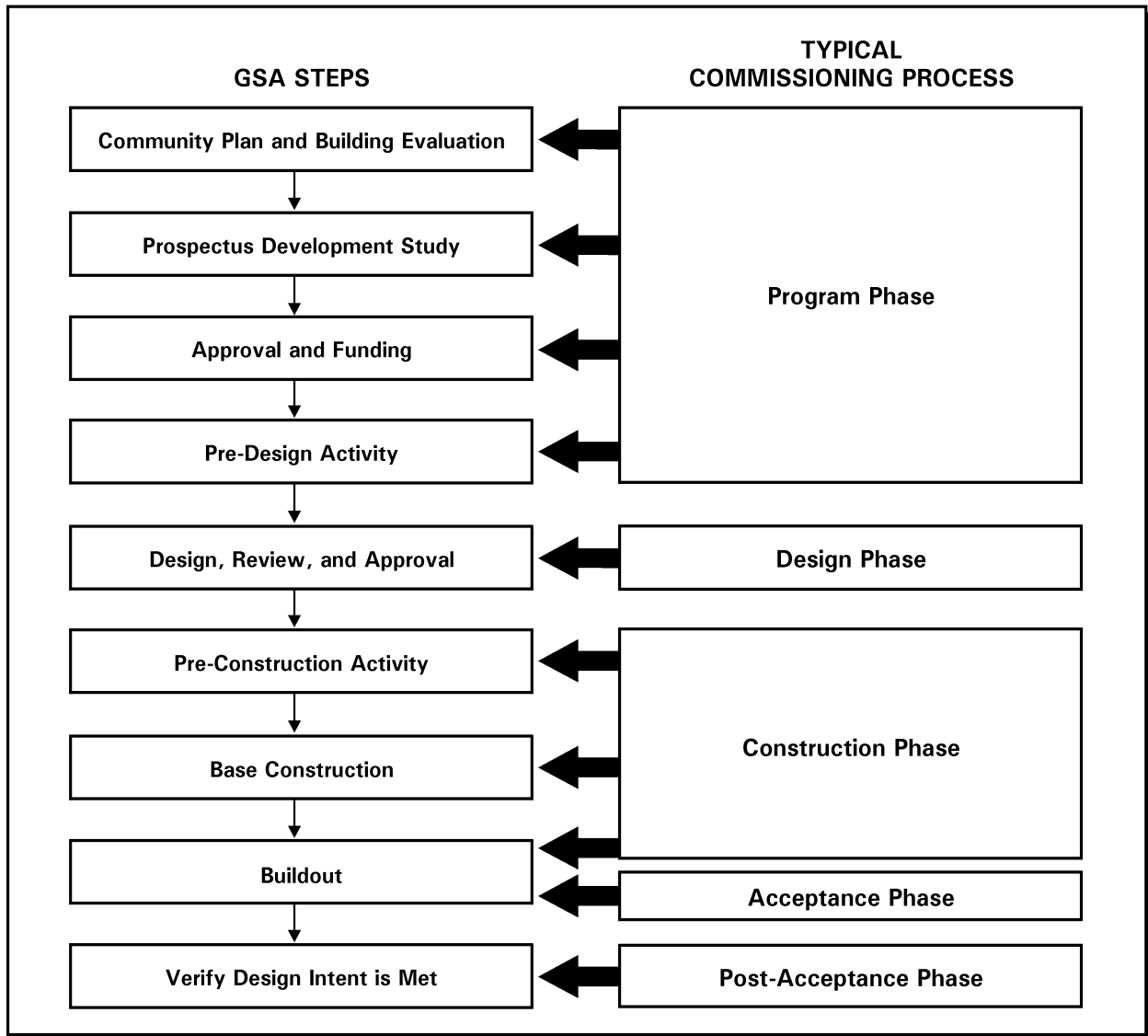
Although GSA's building construction process is not specifically a building "Commissioning" Program, it includes clearly defined steps which can be directly related to the commissioning process as defined.

Figure 2-2 represents the correlation of the GSA building construction process and the building commissioning process. As part of the Verification of design intent, GSA performs many activities which can be directly related to the Commissioning Process. For this reason, post-acceptance is included as a separate step in the GSA process.

Note that in the GSA building process, the construction step includes pre-construction activity, base construction, and buildout. Acceptance takes place after buildout but prior to occupancy. The Post-Acceptance Phase includes the seasonal functional performance tests that take place over the first year of occupancy as well as the post-occupancy review that GSA performs two years after the building is occupied.

For GSA, the process of building commissioning and identification of the Commissioning Authority ideally begins at the first step, Community Planning and Building Evaluation, and continues throughout the entire project. For major projects, the Commissioning Authority should be hired prior to the architect and be involved with the project from the outset, allowing the Commissioning Authority to have input into the project budget and timeline, as well as providing guidance to ensure that all commissioning costs and milestones are included.

**Figure 2-2
GSA Building Process**



The following section provides an overview of the general work performed during each of the five phases of the building commissioning process.

Program Phase

The Program Phase lays the foundation for the other phases and defines the scope of the project based upon the agency's requirements and future expectations of the building. During the Program Phase, the operational, energy, and occupant requirements for the finished building are defined; construction budgets are planned; and a project management plan is developed. Particular emphasis is placed on documenting the function of the facility, identifying occupancy requirements, and developing a budget that incorporates life-cycle cost-effective energy efficiency components.

At this point, the Construction Manager, Architect/Engineer (A/E) firm and the Commissioning Authority are hired. In the case of GSA, an outside consultant with building commissioning experience is usually hired as the Commissioning Authority. As part of the project management plan, the roles and responsibilities of GSA, the Construction Manager, A/E firm, the Commissioning Authority, members of the design team, and contractors must be defined for the commissioning process. It is critical that the lines of communication are established at the very beginning, and that all team members understand the expectations of the project building, and the decisions that must be made to achieve this goal.

The most important documents generated during this phase are the project management plan prepared by the Construction Manager, initial statement of design intent prepared by the A/E firm, and a preliminary Commissioning Plan prepared by the Commissioning Authority. These documents form the guidance for building construction and form the basis by which the project will be judged as a success. Refer to Chapter 5 for additional details of the Program Phase.

Design Phase

During the Design Phase, the design of the building (including all components and systems) is completed. The Commissioning Authority reviews the design to assure that it is in accordance with the design intent. Specifications and contract documents are then prepared. In addition to these documents, the commissioning process requires that all changes to the initial design intent be documented, reviewed, and approved by the Commissioning Authority and owner.

The Commissioning Plan and commissioning specifications are also completed during the Design Phase. The Commissioning Plan details each Commissioning Team member's roles and responsibilities,

procedures for verification of functional performance testing, project organization, staffing and commissioning schedule. The Commissioning Plan is used to develop commissioning specifications that become part of the contract documents.

The commissioning specifications detail the commissioning process and the scope of work for all participants including contractors and vendors. The specifications also identify the skills and qualifications required of all members of the Commissioning Team. They should include clear descriptions of the level of rigor by which each component and system will be tested and what the performance standards will be. Refer to Chapter 6 for additional details of the Design Phase.

Construction Phase

During the Construction Phase, the building shell is constructed; utility services are established; and all systems and components are installed, undergo testing, and begin operation. Pre-functional performance testing is performed for all systems and components, and upon successful completion, they are certified ready for commissioning. All responsibilities and schedules for functional performance testing are determined. O&M information, including warranties, is obtained for all components and equipment. Field inspections are regularly undertaken to assure that the construction complies with the design plans. The Commissioning Plan is then modified to reflect all changes that are made to equipment and components during construction. Refer to Chapter 7 for additional details of the Construction Phase.

Acceptance Phase

During the Acceptance Phase, functional performance testing is conducted to verify that performance of all integrated systems meets the specified objectives defined in the design intent. Because total building performance is a function of the integrated performance of all components, functional performance testing ensures that equipment and systems are installed correctly, tested, and adjusted so that they operate at maximum efficiency according to the specifications both individually and cooperatively. This testing is intended to document the completion and performance of all components, equipment and systems. All systems should be tested and calibrated prior to functional performance testing; the contractor may be financially responsible for any retesting necessary due to failed functional performance tests during the commissioning process.

In addition to a complete and functioning building, building system O&M documentation submitted by contractors is reviewed and approved by the Commissioning Authority. Also, all documentation developed during the commissioning process must also be assembled by the Commissioning Authority. Additionally, the facility maintenance staff is trained on all O&M procedures by the equipment vendors and others, as specified by the Commissioning Authority. Refer to Chapter 8 for additional details of the Acceptance Phase.

Post-Acceptance Phase

The actions of the post-Acceptance Phase are intended to respond to the dynamic changes that occur in a building over time through the normal use and operation of a building. As an extension of the Acceptance Phase, if components, equipment, and systems could not be sufficiently tested to verify seasonal operation during the Acceptance Phase, functional performance testing should be continued for each seasonal variation. Documentation of any changes in use, equipment, occupancy over time, and user feedback begins. In addition, a program of periodic indoor environmental and energy performance testing is established. GSA requires that a post-occupancy review occur after two years of occupancy to ensure that the building is operating as defined in the design document. This verification should be based on appropriate testing and operator and tenant interviews. The basis for assuring compliance with the design intent cannot be established by a simple building acceptance walk-through, but should be dependent on the equipment test results. Refer to Chapter 9 for additional details of the Post-Acceptance Phase.

Chapter 3

DEFINING THE TEAM AND ITS RESPONSIBILITIES

A typical commissioning team should include:

- Commissioning Authority,
- Representatives of the building owner/agency,
- Construction Manager,
- A/E Design Team,
- Contractors and equipment vendors, and
- O&M personnel.

Each member of the commissioning team has specific responsibilities to ensure that the commissioning process is completed according to the Commissioning Plan and design specifications. The following descriptions provide typical responsibilities for commissioning team members. More detailed lists of responsibilities can be found at the end of this document under Additional Resources, particularly *ASHRAE Guideline 1-1996* and *Model Commissioning Plan and Guide Specifications*.

The Building Owner/Agency

The building owner/agency defines the overall vision for the use of the building; establishes operational requirements and commissioning objectives; defines the Commissioning Team; establishes the construction budget; and determines the role of O&M staff in the commissioning process.

For major projects, GSA typically retains a Construction Manager and Commissioning Authority.

The Commissioning Authority

The role of the Commissioning Authority may be performed by the Construction Manager themselves, or a subcontractor of the Construction Manager depending on the specific site requirements.

The Commissioning Authority is responsible to the owner/agency to enforce and verify that the design intent of the building is satisfactorily achieved. The Commissioning Authority is comprised of building commissioning experts who maintain a broad understanding of all aspects of building commissioning.

Figure 3-1 includes the typical qualifications for a Commissioning Authority. Specific tasks performed by the Commissioning Authority include:

- Preparing the Commissioning Plan, test plans, and final report (in some scenarios, these documents are created by the Contractor's test engineer and approved by the Commissioning Authority);
- Submitting progress reports to the Agency;
- Coordinating the Commissioning Team and work schedules;
- Reviewing submittals and O&M manuals for completeness as a related to the commissioning plan;
- Reviewing commissioning specifications;
- Coordinating, overseeing, and documenting prefunctional and functional performance tests;
- Establishing procedures on how and what to document;
- Reviewing training materials and procedures;
- Reviewing record drawings and documentation; and
- Recommending acceptance or nonacceptance to the design team or coordinating design professional and Construction Manager.

Figure 3-1
Qualifications of a Commissioning Authority

- Knowledge of building commissioning techniques and practices: such as, air and water balancing of HVAC systems; sound and vibration measurement; systems performance documentation; systems performance versus design criteria evaluation; system components operation verification; and functional performance testing.
- Able to perform all building commissioning functions and know the basic O&M requirements of standard building systems.
- Maintains a thorough knowledge of applicable building codes and standards.
- Complete familiar with the design intent and installation of the building systems and equipment.
- Has a history of successfully completing projects involving troubleshooting and/or performance verification of building systems.
- Experience in writing of functional performance test plans and overseeing building system tests.
- Familiarity with testing instrumentation.
- Experience in planning and delivery of training to operating and maintenance staff.
- History of successful performance.

The Commissioning Authority coordinates and documents the final evaluation of the systems' capabilities to meet the design intent; reviews and comments on technical considerations during all phases of design and construction that impact the eventual O&M of the building; and reviews and comments on vendor-prepared and contractor-prepared training documents and procedures before they are delivered to the building O&M staff and facility manager.

The Design Team

The design team, composed of the architects and engineers, prepares the design document which reflects the design intent of the building owner/agency, so that the installed systems can be tested against a predetermined criteria and the commissioned building operates as intended.

In most projects, the design team is led by an A/E firm designated as the coordinating design professional or "Designer of Record". In such projects, the role of the coordinating design professional is to receive and distribute information for review by the commissioning team during the Design Phase; set a coordinating timetable; facilitate communication between members of the commissioning team; receive and issue all final letters of design acceptance; and recommend design acceptance or nonacceptance to the owner.

The primary role of the design team is to translate the building owner/agency's requirement into a technical design intent; ensure that commissioning is included in the design specifications; review and approve shop drawings, original mockups, record drawings, control strategies, O&M manuals, and documentation; provide guidance on construction activities; and attend prefunctional performance tests and review test reports. Relative to commissioning, the design teams responsibilities vary depending on the specific project and contract, but may include:

- Inspecting the design for code compliance, design credibility, and reviewing proposed materials and equipment.
- Developing design narratives and detailed sequences of operation for all systems.
- Ensuring that O&M manuals are prepared as specified for each building system. These manuals must be detailed to include information relating to all equipment and how it interfaces with other equipment and controls. These manuals contain all test results, including test and balance reports.

- Reviewing the Commissioning Authority's commissioning and test plans when requested by the Commissioning Authority. The design team may increase the test rigor, however, any recommendation to reduce rigor need not be accepted by the Commissioning Authority.
- Coordinating the O&M training, which is provided by the various vendors and the design team's suppliers. This task may also be assigned to the Commissioning Authority.
- Responsibility for integrating the component maintenance manuals into a comprehensive maintenance plan, which requires collection of the O&M materials from the various contractors and suppliers. They may also approve any and all maintenance plans before incorporating them into the final product.
- Ensuring that the facility and systems meet all applicable codes.
- Ensuring that the building's interior design addresses indoor air quality concerns and that the comfort of the occupants is addressed.

The Construction Manager

Although a Construction Manager is used by GSA, this role may be performed by an agency's QA team, as is the case for the U.S. Army Corps of Engineers. The Construction Manager provides management, technical, and administrative expertise during Design and Construction Phases to ensure that building owner/agency's goals relating to schedule, budget, scope, and quality are met. The Construction Manager responsibilities typically include:

- Providing management expertise, such as monitoring performance of contractors, controlling schedules, and overseeing financial accounts.
- Coordinating with the Commissioning Authority in development of the Commissioning Plan.
- Performing quality control functions, particularly in the areas of design reviews for constructability and inspection.
- Assisting the building owner/agency project team and the Commissioning Authority with administrative tasks, including documentation, recordkeeping, payment validation, and submittal and change order processing.
- Providing technical expertise such as testing, cost estimating, and resolving disputes and claims.
- Advising the building owner/agency contracting officer immediately of any project-related problems which are beyond the Construction Manager's ability or responsibility to resolve.

In general, the Commissioning Authority and the Construction Manager have different skills. A Commissioning Authority has technical background and familiarity with the commissioning process including verification techniques and functional performance testing, system equipment and O&M knowledge. The Construction Manager is responsible for managing the construction process and assuring completion of the project on time and within budget. However, with the proper qualifications and experience, the Construction Manager could fill the role of building Commissioning Authority. In some cases, the Construction Manager may hire a subcontractor to act as the Commissioning Authority, resulting in no additional contracts management responsibilities by the agency.

The Contractors

Depending on the nature and size of a construction project, many different contractors may be involved. The various contractors may include the building contractors (general, mechanical, and electrical), the testing, adjusting and balancing contractor, the building automation controls contractor, and others as required by the contract documents. Each contractor is responsible for constructing their respective portion of the building in accordance with the contract documents. Not every contractor will be simultaneously involved with the commissioning process during the construction phase, and scheduling will be carried out by the Construction Manager.

The contractors perform work and supply equipment and systems as stated in the respective contracts; provide documentation as specified and as requested by the Commissioning Authority; coordinate QA and work schedules; perform pre-functional performance test and component tests; perform functional performance tests; fine-tune and adjust equipment and systems; and provide manuals and training for O&M staff.

As a member of the Commissioning Team, the responsibilities of the various building contractors include:

- Preparing and submitting documentation of their respective equipment and systems to be integrated into the overall Commissioning Plan and project schedule. For the Commissioning Plan, the contractors must explain the protocol that they intend to use for each piece of equipment and for the integration of the system as a whole.
- Submitting shop drawings detailing equipment layout as outlined in the specifications.
- Performing equipment start-up and testing with the manufacturer.

- Reviewing and performing all specified tests under the oversight of the Commissioning Authority. The tests are performed with currently certified test equipment. Certifications are furnished to the Commissioning Authority, when requested.
- Correcting system deficiencies at their own expense. If systems fail a second time, the contractor may be backcharged for the Commissioning Authority's and A/E firm's time for the third test.
- Obtaining all permits, code-required inspections, and final certifications. Upon any code-inspections, the entire system design process must be documented and the design engineers notified.
- Preparing all record drawings made from an original set that has been marked up throughout the duration of the project. These drawings must show all work as it was actually installed, showing change order revisions, field changes required to meet the working conditions, and any other items that will affect or be reflected in the O&M of the facility.
- Obtaining from the manufacturers and subcontractors all warranties and guarantees and forwarding them to the owner using the specified procedures.
- Organizing the O&M manuals from their subcontractors, suppliers, and manufacturers and submitting them to the design professional for implementation into the final O&M manuals that will be distributed to the building's O&M staff.
- Performing specified facility staff training.

In the end, the prime contractor is responsible for all system performance issues for all contractors. The owner, Commissioning Authority, Construction Manager (if hired separate from the contractor) assist in, and document the contractor's demonstration that all systems comply with contract documents.

The Testing, Adjusting and Balancing Contractor

Testing, adjusting and balancing (TAB) contractors perform their work after other contractors have substantially completed equipment installation. The TAB contractor primarily focuses on ensuring the proper installation and balancing of the HVAC and water systems to achieve the required occupancy comfort and air quality. It is important that adequate time is provided for the TAB contractor to perform a complete and proper evaluation and system adjustment. Although, it is not necessary for the Commissioning Authority to be present at every test, all documentation and test results should be

submitted to the Commissioning Authority for review and incorporation into project documentation. As a member of the Commissioning Team, the TAB contractor have the following responsibilities:

- Prepare a testing and balancing plan outlining the total work effort that will be integrated into the overall Commissioning Plan. This is typically reviewed and approved by the Commissioning Authority.
- Perform and document all specified preliminary tests, including hydronic, pressure, temperature, air flow, and duct tests and submit them to the design team and the Commissioning Authority for the record.
- Test and balance all HVAC equipment and air and water flows and forward the results to the design team and the Commissioning Authority.
- Rebalance the total system after completion of the interior build-out as specified. This might require multiple balancing of the HVAC systems, to ensure the original design intent for the building is met.
- Prepare the testing and balancing report along with the O&M documentation and submit it to the commissioning team.
- Participate in a spot field check of the TAB readings, as directed by the Commissioning Authority.

The Building Automation Controls Contractor

Building automation controls contractors have the following commissioning responsibilities:

- Submit shop drawings and equipment descriptions, including full, detailed control drawings, sequences of operation, and maintenance plans to the design team and Commissioning Authority for approval. They must confirm software, hardware, and access ports for testing, maintenance and mode changes.
- Perform necessary factory testing of all hardware and software and submit certification to the design engineer and the Commissioning Authority.
- Install control systems, and verify the systems and service access to the various system components.
- Perform and document all specified tests, including hydronic, temperature, pressure, and compressed air, that relate to automatic building control systems, and forward all test results to the Commissioning Authority.
- Perform start-up and functional testing of all control systems as they relate to individual subsystems and integrated systems. Perform and document total system start-up and testing and supply certification to the design team and the Commissioning Authority.

- Perform training under the direction of the design team outlining system component operation and furnish training and operating manuals for the operators.
- Prepare and submit control O&M manuals to the building owner/agency, Commissioning Authority or the design engineer for integration into the overall project O&M manuals.
- Witness and execute, as specified, all seasonal system operations tests and verify the operations and system competency for the design engineer.
- Test the entire system for serviceability and performance, and correct any deficiencies.
- Verify and adjust setpoints, reset schedules, and gain constants for actual installation, including seasonal testing and interconnections with other systems such as life safety and security.
- Document all changes, update the O&M manuals and record drawings, and forward all documentation following the designated protocol.

The Suppliers

The suppliers of major systems or equipment are required to support the Commissioning Team through the contractors they supply products to in the following manner:

- Provide detailed start-up procedures to the Commissioning Authority.
- Some scenarios also require preparing and submitting to the contractor a proposed system or equipment Commissioning Plan that is integrated into the overall project schedule. In this plan, the suppliers must show their factory equipment test, shipping and receiving dates for equipment, and any other protocols as outlined in the project documents. Most often, however, this test plan is developed by the Commissioning Authority.
- Provide all requested submittal data from the design, construction or commissioning teams.
- Assure a complete submission to the contractor of equipment, any special tools, parts list, installation instructions, and warranty information.
- Review and analyze for best value, the design concepts and documents to verify that the designer is using the newest and most recently updated equipment that is acceptable to the owner and meets the facility's requirements.
- Perform all factory witness testing plus all other specified preliminary testing in the presence of the building owner/agency and designated commissioning team members.
- Perform and document their system start-up and testing in accordance with the manufacturer's specifications and Commissioning Authority's recommendations.

- Perform system training and component operation along with furnishing O&M manuals to the contractor for integration into the overall O&M manual, under the direction of the design engineer or other designated authority.
- Provide the required warranty service as outlined in the project documents.

The Operation and Maintenance Staff

The O&M staff assist the commissioning team in the following areas:

- Define O&M requirements of the building.
- Participate in design review for O&M impacts.
- Develop maintenance manuals, record drawing and documentation requirements.
- Define training program requirements.
- Conduct functional performance testing.
- Attend contractor and vendor training sessions.

Chapter 4

MANAGEMENT APPROACH

Proper coordination of efforts, for which the Commissioning Authority is responsible, is the key to ensuring the successful commissioning of a building. In the building commissioning procedure, all parties—the building owner, the design team, and the contractors—must effectively coordinate their respective activities to produce a sound, energy efficient building. From the start, the owner/agency must clearly communicate its intentions for the building so that the architect and engineer can deliver the best design. From this foundation, the architects and engineers need to document and explain to owner/agency and the contractors the intent behind the proposed designs so that owner/agency can see that its needs are being addressed and the contractors can implement the design as described. The contractors must properly implement the building design and also notify the design team when the design can not be met. As the system components are installed, they need to be tested and balanced to ensure a proper integration of all steps. As the systems are installed, the building O&M staff need to be trained on how to maintain the systems.

Since many of these activities are occurring simultaneously, it is critical that they be managed properly to commission the building on-time, and on-budget. Management of all the activities is the responsibility of the Commissioning Authority, and includes the following areas:

- Project Authority
- Project Communication
- Planning and Scheduling
- Commissioning Plan Implementation
- Quality Control
- Documentation
- Project Closeout.

Project Authority

Identification of the Authority of each member of the commissioning team will not only clarify each member's responsibilities, but reinforces the role of the Commissioning Authority as the management body.

Identification of project authorities must occur in the earliest stages of the project as possible, and include:

- Provisions for establishing a Commissioning Authority;
- Clearly defined jurisdiction of the Commissioning Authority, A/E contractors, and owner/Agency;
- Cooperation between Commissioning Authority, A/E contractors, and suppliers;
- Establishment of effective lines of communication;
- Clearly defined building project and commissioning program objectives; and
- Methods for the implementation of planning measures.

Particular attention should be made in ensuring that the A/E responsibilities assigned for the Construction Phase and those of the Commissioning Authority are clearly delineated. The specifications should ensure that the lines of authority are established early in the project.

Project Communication

Since the designers, owner's project manager, construction manager, Commissioning Authority, and contractors must all work together throughout the project, clearly defined means of communication are essential. Part of the success of commissioning depends on the effectiveness of the communications to expedite all matters quickly and efficiently.

Two different lines of communications involved in the commissioning process are:

- Formal communication that relates to all reports, official correspondence, lists of deficiencies, approvals, enforcement of authority and similar documents; and
- Informal or coordination type of communication among all parties involved.

A document describing the communication protocols and paths should be developed.

Project Planning and Scheduling

The entire commissioning process should be thoroughly organized and planned at the outset of the project. All commissioning activities should be scheduled by the Contractor or Construction Manager with assistance of the Commissioning Authority, as soon as practical after the project is initiated.

Each commissioning team member should be provided with a copy of the commissioning schedule by the Commissioning Authority contractor. The schedule is developed to help coordinate the tasks involved in the commissioning process with the construction work so there are no delays caused by conflicting time frames. If the commissioning process is planned out carefully, the tasks should proceed smoothly and, ideally, with no interruptions to the construction work.

Changes to the schedule by any team member or by the Commissioning Authority should be immediately communicated to those members directly affected by the changes. This communication should then be followed up by sending to all team members a written communication regarding the changes along with a revised schedule.

Following are some typical considerations when developing the schedule:

- The integrity of the building envelope should be evaluated during its construction, not after the walls and roof are complete.
- Pipe and duct insulation should be examined before the ceiling is erected. Terminal units should also be inspected and tested before the ceiling is installed if the ceiling does not allow easy access.
- Check lighting systems during installation to ensure that proper components are being used.
- Check the placement of occupancy or daylighting sensors to avert potential placement problems.
- Perform testing and balancing work after the building is completely enclosed. HVAC systems functional testing should not be performed until the test and balance is completed.
- Controls should be tested after all points are installed, calibration activities are executed, and the system or equipment to be controlled is positioned and start-up procedures are finished.
- Design intent documents and equipment submittals, and often parts of the O&M manuals must be collected prior to developing pre-functional and functional performance tests.
- All systems and equipment must undergo normal start-up procedures before the functional performance tests can begin.

Commissioning Plan Implementation

As one of its roles in managing the commissioning process, the Commissioning Authority must make every effort to ensure that building construction and system installations are performed as required and in a timely fashion. In the event that problems arise which prevent the normal order and sequence for

executing a project, the Commissioning Authority should work with the contractor or Construction Manager to redirect the schedule to maintain consistent progress, as much as possible, on the project.

Occasionally, problems will arise which will require a change in the original building design. In this case, the design team needs to be notified and involved in the resolution. System troubleshooting is the sole responsibility of the contractor. However, the Commissioning Authority assists in identifying sources of malfunctioning systems through the normal testing and documentation process. The A/E may also be consulted, when necessary. For example, electric duct heaters often are installed by sheet metal contractors, purchased by the mechanical contractor, wired by electricians, with the control circuits under the supervision of the control contractor. If the duct heaters do not function, any or all of these contractors could be involved in locating and repairing the problem. The prime contractor is the final point person and the party directing the effort. It is normally not in the jurisdiction of the Commissioning Authority to determine the cause of the problem nor to determine the responsible party(s).

Quality Control

Proper commissioning will ensure quality control by eliminating reporting errors, ensuring correct system installation, enabling verification of building system operation before turnover, and mandating proper O&M documentation.

The traditional commissioning management scenario is described in this guide, where the Commissioning Authority writes the functional tests, and oversees, witnesses and documents their execution by the contractors. Pre-functional checklists and start-up, on the other hand, are conducted and documented by the contractors themselves, with input into the documentation rigor and format being provided by the Commissioning Authority prior to installation. In this scenario, quality control is achieved by:

- Approval by the Commissioning Authority of the contractor's start-up and initial checkout plans;
- Random visits of the Commissioning Authority during installation and start-up;
- Approval by the Commissioning Authority of prefunctional checklists and start-up reports;
- Spot checking of critical prefunctional checklist items, including sensor and actuator, calibrations, prior to functional testing;
- Writing, witnessing and documenting by the Commissioning Authority of the execution of the functional performance tests by the contractors.

Another commissioning management scenario that has been used successfully, puts all of the burden of systems testing, including the development and documentation of testing procedures, on the contractor and his/her test engineer. In this scenario, the commissioning authority receives start-up reports and all functional testing documentation from the contractor's test engineer. These documents are reviewed and approved by the commissioning authority. Quality control is achieved by:

- Approval by the Commissioning Authority of the contractor's start-up, initial checkout and functional testing plans and procedures,
- Random visits of the Commissioning Authority during installation and start-up,
- Approval by the Commissioning Authority of prefunctional checklists and start-up reports,
- Commissioning Authority witnessing parts or all of the primary systems functional testing and a sample of other systems testing by the contractors, and
- Commissioning Authority spot checking of functional test results by repeating desired portions of tests.

From the outset of the commissioned project, the design team, contractors, and all other parties should be made aware that the Commissioning Authority will verify system installation and test results performed by others. Verification should discourage shortcuts and performance of substandard work. In the event that discrepancies are found in test results, spot-checks of that particular system should increase and the responsible party is held liable for correcting the problem.

Commissioning Documentation

Thorough documentation is one of the primary differentiating components between the more random, decentralized quality assurance and quality control methods and the formal commissioning process. Documentation is developed at each design and construction phase (as described in more detail in each section of this guide), and should be specified in the contract documents. There are four main types of documentation:

- **Design documentation**, such as design intent documentation, drawings and sequences of operation;
- **Process documentation**, such as commissioning specifications, execution plans and schedules, progress reports, meeting minutes, etc., which assist in executing the commissioning process;

- **Verification documentation**, such as test plans, and issues logs, which is used for “proving” that systems have been installed and are working in accordance with the contract documents; and
- **O&M documentation**, such as equipment maintenance manuals, which are used on an ongoing basis by the operators to control and maintain the building systems.

The design documentation is generally developed by the A/E, with some focused review by the Commissioning Authority. The Commissioning Authority will typically include parts of the design documentation (design intent, sequences, etc.) in their verification documentation and ensure that it is appropriately inserted in the O&M documentation.

The process and verification documentation is compiled in an organized manner as the commissioning process continues by the Commissioning Authority. The O&M documentation is submitted by the contractors and reviewed by the Commissioning Authority, but is typically compiled and organized by either the A/E or the contractor.

The primary documentation items for each of the four groups are listed below.

Design Documentation

Owner’s program
Design intent
Drawings
Sequences of operation
General specifications
Equipment submittals
Control drawings and points list
Design reports
Architect’s supplemental instructions
Change orders

Process Documentation

Commissioning specifications and test requirements
Commissioning plan
Report forms
Schedules
Meeting minutes
Progress reports
Communications

Conflict and resolution record
Start-up and testing plans
Training Plans

Verification Documentation

Construction observation reports
Deficiency and issues log
Start-up and checklist reports
Test reports (factory, contractor and CA generated)
Training record
Test and document approvals
Final commissioning report

O&M Documentation

Warranties
Equipment O&M manuals
As-builts, especially control drawings
Insertion of selected design documentation by equipment (design intent, and records, especially control drawings and sequences)

Project Closeout

The Commissioning Authority determines when the commissioning process specified in the contract documents has been satisfactorily completed, and when to submit the final test report forms and other documentation to the owners.

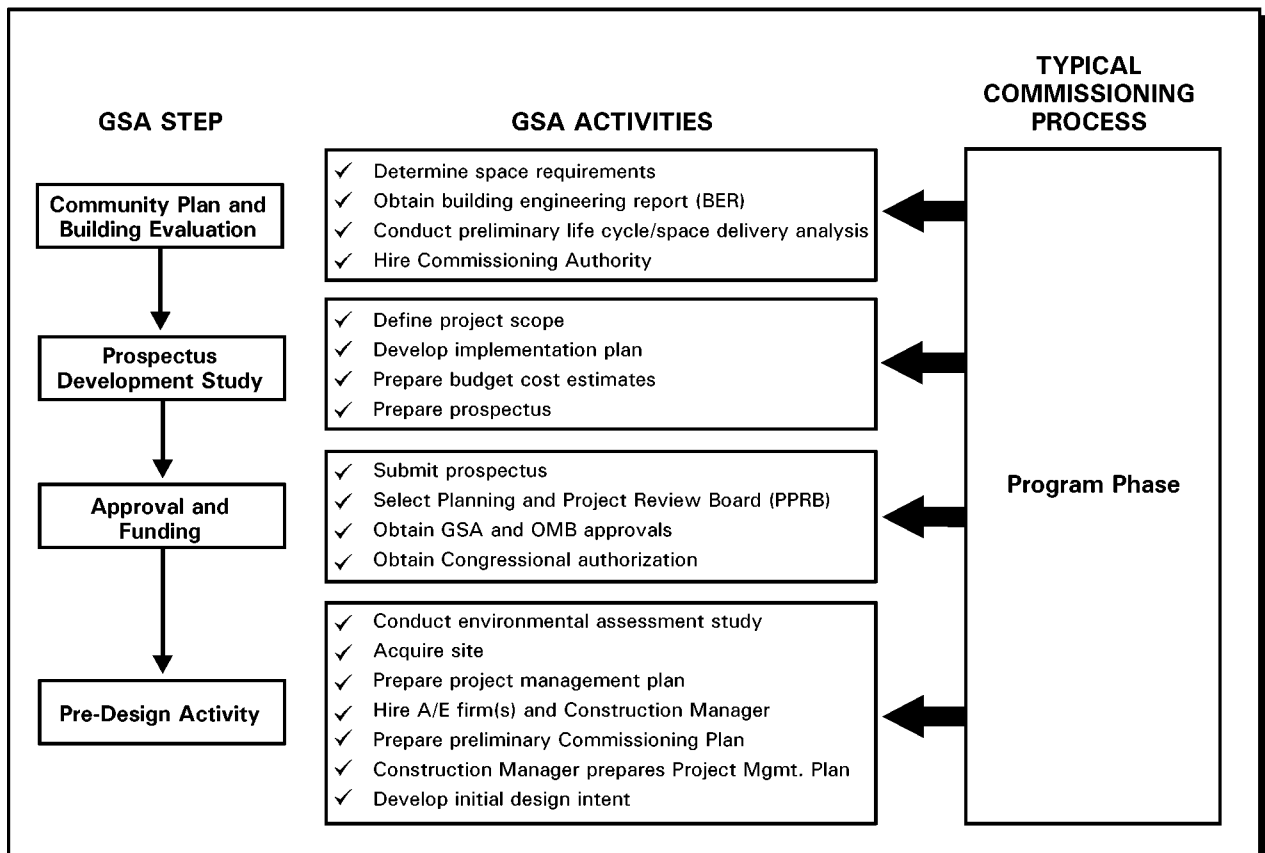
As part of the official project turnover, the quality of the work must be reviewed to determine whether or not it is within the specific guidelines and meets the criteria specified in the design intent. Most importantly, the Commissioning Authority must be satisfied that the commissioning process has been performed accurately and professionally, and that the proper commissioning procedures have been followed, that all readings and documentation are correct, and that the installed systems will operate as designed and without complaints from the owner or his tenants. Often there are lingering issues or deficiency items that cannot be fully resolved until a later date (e.g., seasonal testing, equipment parts ordering, etc.). The “final” commissioning report and recommendation for system acceptance may still be made, subject to unresolved issues.

Chapter 5

PROGRAM PHASE

The three primary objectives during the Program Phase include: first, to set building commissioning parameters, which outline the equipment, building systems (including architectural and structural systems), systems controls, and other issues that will be commissioned; second, to determine general responsibilities and documentation requirements during all phases of design, construction, and occupancy; ensure that project team members are made aware and understand these requirements and their responsibilities; and set a frame work for commissioning during each phase; and third, to document the base information from which to develop the design intent and benchmark information to evaluate final performance including: occupancy requirements; design assumptions, building construction, building loads/zoning, and building utilization; and cost consideration and design compromises. As seen in Figure 5-1, the first four steps of the GSA process address these three objectives of the Program Phase .

Figure 5-1
GSA Program Phase Building Process



Procedure

The Commissioning Authority will evaluate the owner's requirements in areas assigned and verify that the design intent will fulfill the owner's needs. The Commissioning Authority will generally only be assigned to cover HVAC, electrical, indoor air quality, energy, O&M, and possibly shell and plumbing issues. The Commissioning Authority also will clearly define the commissioning roles and responsibilities of the design and construction teams during the design process.

Evaluation

Typically the Commissioning Authority will review the building requirements. They should include information regarding building population, required physical areas for activities and equipment or other special needs, thermal environment requirements, lighting and power requirements, and budget constraints for the proposed building. The Commissioning Authority will provide input as to whether the proposed systems are adequate for the building and if the operating and maintenance staff have the ability to operate and maintain the proposed systems and equipment.

Design Concepts

The design team will develop schematic drawings of conceptual designs that address the requirements of the design intent and present them to the owner for review and acceptance. A few of the design considerations and/or problems that should be resolved during this phase, for which the Commissioning Authority may provide input and review, include:

- Is equipment too large for the mechanical rooms?
- Will there be indoor air quality problems?
- Where are water and sewage mains located?
- Where are intake and exhaust openings located?
- Are there any code exception problems?
- Is energy usage being minimized?
- Is operability being maximized?
- Is maintainability being simplified?
- Are the systems/equipment selected the most life-cycle cost-effective?
- Were at least three options considered?

Documentation

The Commissioning Authority will develop the design documentation outline and requirements and specify any particular forms that are required for documenting the commissioning process during design.

Program Pre-Design Phase

In the program or pre-design phase, the preliminary Commissioning Plan outline presents the initial concepts of the various building systems that are being developed and reviewed. It establishes the Commissioning Team member's responsibilities and the commissioning process required for various systems, including the scope of the process and the potential time required for completion during design. It also establishes a budget that takes into account the commissioning process, and includes project management costs, Commissioning Authority fees, contractor costs relative to their commissioning requirements, and any incremental costs associated with the energy efficient equipment used in the building design.

An initial scoping meeting with the commissioning team is held to review the schedule and Commissioning Plan outline and identify the major responsibilities of each team member. These responsibilities will then be clearly outlined in the final Commissioning Plan. The agenda and notes from the scoping meeting should be attached to the Plan.

Chapter 6

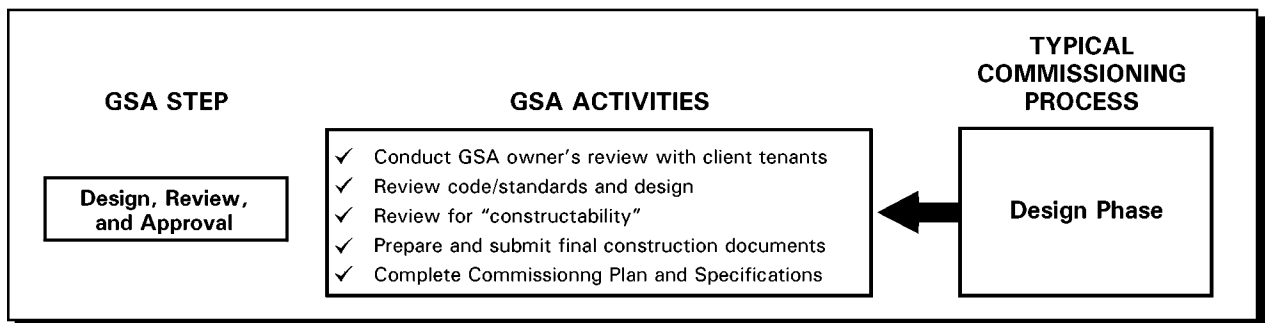
DESIGN PHASE

During the design phase there are four primary commissioning activities:

- Develop design documentation (design and operating intent);
- Perform commissioning-focused design review(s);
- Develop a draft Commissioning Plan for the construction phase; and
- Develop commissioning specifications for the construction phase.

The Commissioning Authority or the A/E are assigned to coordinate these activities under the overall direction of the A/E. The A/E has the sole responsibility for the design of the building systems including the GSA activities listed in Figure 6-1.

Figure 6-1
GSA Design Phase Building Process



Design Documentation

The design documentation includes the design intent and the basis of design. Specifically identifying and developing the design intent and basis of design provides each party involved, at each respective stage, an understanding of the building systems.

The design documentation differs from traditional specifications in that it provides a more narrative description of the system or issue and "frames" the issue or building component with clear and useful background information. However, design documentation often includes parts of specifications.

For the purposes of commissioning, design documentation includes the salient information from the programming report, the conceptual design phase and from the design and construction process necessary to guide the design, verify compliance during construction, and aid building operations. Design documentation consists of two dynamic components: design intent and the basis of design.

Design Intent. The design intent is a dynamic document that provides the explanation of the ideas, concepts and criteria that are considered to be very important to the owner. It is initially the outcome of the programming and conceptual design phases. The design intent document should cover the following, for each system, major component, facility and area:

- Objectives and functional use of the system, equipment or facility
- General quality of materials and construction
- Occupancy requirements
- Indoor environmental quality (space temperature, relative humidity, indoor air quality, noise level, illumination level, etc.)
- Performance criteria (general efficiency, energy and tolerances of the indoor environmental quality objectives, etc.)
- Budget considerations and limitations
- Restrictions and limitations of system or facility
- *Very general* system description

Basis of Design. The basis of design is the documentation of the primary thought processes and assumptions behind design decisions that were made to meet the design intent. The basis of design describes the systems, components, conditions and methods chosen to meet the intent. Some reiterating of the design intent may be included. The following should be included in the basis of design:

- Specific description of systems, components and methods for achieving the design intent objectives. (For example, for a rooftop air conditioning unit include: why this system was chosen above others, details of size, efficiencies, areas served, capacity control details, compressors, coils, dampers, setpoints, filters, economizers, minimum ventilation control, control type, noise and vibration criteria, tie-in to other systems, sequences of operation under all modes of operation, control strategies, etc.)
- Equipment maintainability
- Fire, life, safety: criteria, general strategy narrative and detailed sequences

- Emergency power control and function
- Energy performance
- Ventilation strategies and methods
- Complete sequences of operation, including setpoints and control parameters
- Schedules
- Permits and fees
- Codes and standards applicable
- *Primary* load and design assumptions
 - Diversity used in sizing
 - Occupant density and function
 - Indoor conditions (space temperature, relative humidity, lighting power density, ventilation and infiltration rates, etc.)
 - Outdoor conditions
 - Glazing fraction, U-value and shading coefficient
- Information of secondary importance to the commissioning and operation of the building should be documented by the design team, but is not included in the design documentation described here or included in the O&M manuals (e.g., wall R-values, mass, etc.)

The detail of both the design intent and basis of design increase as the design process progresses. In the beginning, the design documentation required is primarily a narrative of the building system descriptions, the purpose of the systems, how the systems will meet those objectives and why this system or method was chosen above others. As the design process progresses, the design documentation includes the basis of design, a specific description of the system and components, its function, how it relates to other systems, sequences of operation, and operating control parameters. Refer to the *Model Commissioning Plan and Guide Specifications* referenced in the Resources section at the back of this guide for sample forms for developing design documentation for representative systems.

Each member of the design team develops the written design intent, basis of design and detailed sequences of operation for the areas of their design responsibility. The architect and Commissioning Authority review, comment on, and approve the submissions.

Design Review

At various phases during the design, as determined in the original commissioning scope, the Commissioning Authority provides a focused design review. The Commissioning Authority compares the design with the interests and needs of GSA as identified in the programming report. The Commissioning Authority also compares the proposed design against the GSA design guide (PBS-PQ100.1, *Facilities Standards for the Public Buildings Service*) for the design areas assigned below. The Commissioning Authority also identifies any improvements that can be made in areas shown in Figure 6-2 below. Though the Commissioning Authority may review the design, they are not *responsible* for design concept, design criteria, or compliance with codes, unless explicitly tasked.

Figure 6-2
Focused Design Review by the Commissioning Authority

Design Area	Review Description
Commissioning Facilitation	Input regarding making the building easier to commission
Energy Efficiency	General efficiency of building shell, building layout, HVAC system types, lighting system type, etc.
Operation and Maintenance	How building O&M can be made easier (accessibility and system control, etc.)
Indoor Environment Quality	How thermal, visual, acoustical comfort or air quality can be improved
Functionality for Tenants	How the design can be changed to improve functionality for the occupants
Environmental Sustainability	How the building materials and systems and landscaping can create less of an impact on the environment
Facility Performance and Design Intent	Identify flaws, oversights, or insufficient detail in the design, relevant to being able to meet the design intent
Life Cycle Costs	Life cycle assessment of options relative to energy efficiency, O&M, IEQ or functionality
Commissioning Specifications	Verify that the bid documents clearly and completely indicate the commissioning process, authorities, requirements for documentation, reporting, communications, testing, training and O&M documentation, etc.

Commissioning Plan for Construction Phase

To be successful, commissioning requires a systematic approach or a “game plan” that defines the commissioning objective and establishes a benchmark for measuring performances. The game plan takes the form of a written plan specifically tailored to the project at hand. This “game plan,” or Commissioning Plan, is a document or group of documents prepared by the Commissioning Authority that defines the commissioning process in the various phases of the project. It is continually evolving and expanded as the design and construction of the subsystems and the building progress. Every portion of the commissioning process should be included in the Commissioning Plan. The plan should include schedules, responsibilities, documentation requirements, all required permitting and associated fees, communication and reporting protocols, and level of testing to be completed.

In addition to the specifications previously identified for the Design Phase, the Commissioning Plan also indicates documentation requirements that each team member must prepare and submit for review to satisfy the building system commissioning requirements. This documentation is prepared and submitted after the building systems contracts are issued and all the necessary specifications of the various building materials and equipment to be installed are available.

Commissioning Specifications for Construction

A critical task during design is to develop complete and clear commissioning specifications for the construction phase. Commissioning specifications are developed by members of the design team as part of the commissioning process during design. The specifications provide information that allows those bidding on the project to understand clearly how the commissioning process works and specifically what role they have in the process. They provide the requirements and process for properly executing the commissioning work with sufficient detail and clarity to facilitate enforcement.

Verification Procedures

The commissioning specifications provide the bidders with a clear description of the extent of the verification testing required. They detail testing requirements including what to test, under which conditions to test, acceptance criteria and acceptable test methods. The documentation, reporting, and general scheduling requirements should also be included. The specifications should name the party responsible for writing, executing, witnessing and signing-off tests. The specifications should also outline

the relationship between start-up, prefunctional checklists, manual functional performance tests, control system trend logs and stand-alone data logging.

The verification procedures which are developed should include all functional performance tests, checklists of equipment or systems to be evaluated, and sample test forms. At a minimum, the functional performance tests which should be verified include, but are not limited to:

- Testing, adjusting, and balancing test performance
- Equipment performance
- Performance of subsystems consisting of combinations of equipment (such as, refrigeration cycle, pumps, chillers, cooling towers, and interconnecting piping)
- Performance of the automatic controls in all seasonal modes
- Integrated system performance
- Performance of all life safety devices and systems as they interface with the subsystems
- Architectural and structural systems performance
- Electrical system performance
- Plumbing system performance

By addressing verification at this point, the Commissioning Authority can elicit comments from the designers and contractors to establish performance standards to be met, ensure that the method of verification is designed for the system and building in a manner to achieve the most accurate measurements, and develop time-tables for the prefunctional and functional performance test so that the project can be completed on-schedule and minimize the impact on contractor timeliness when possible.

Operator Training

O&M is critical to the successful continuation of the design intentions of the commissioning process, and will ensure a longer life-cycle cost to the building. The A/E in consultation with the Commissioning Authority will develop training requirements for O&M staff and include them in the specifications.

O&M Documentation

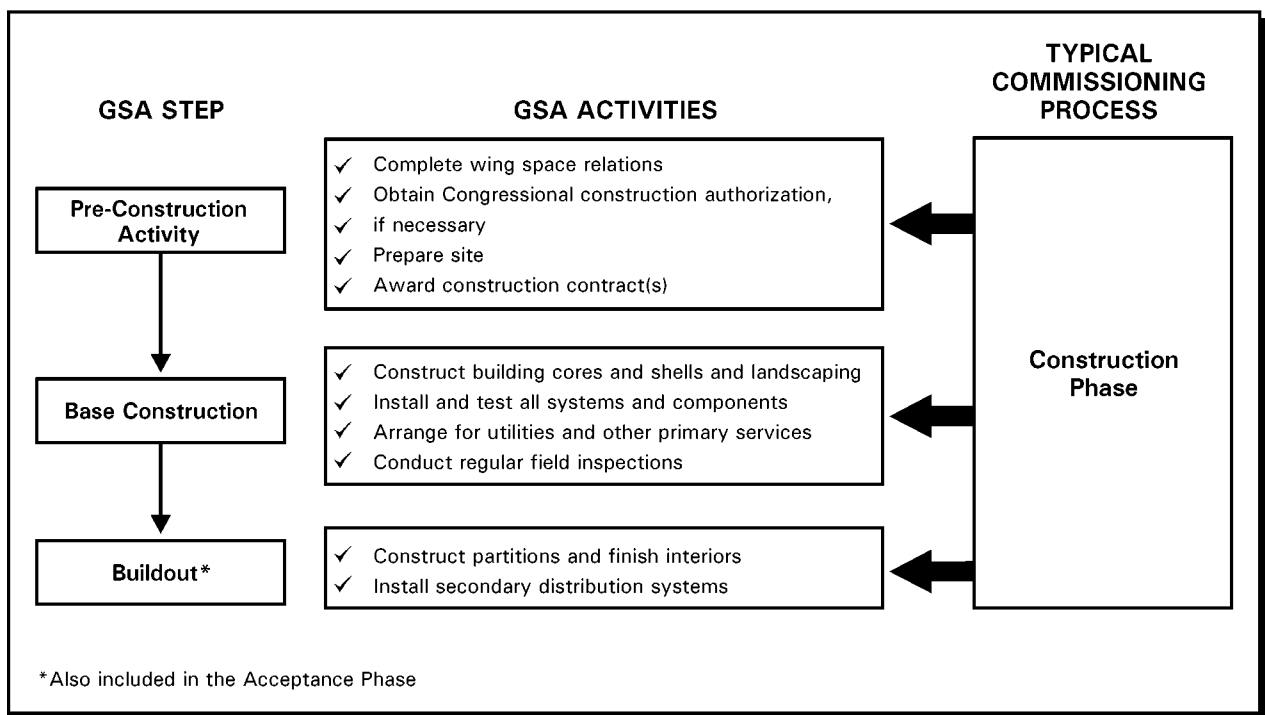
The O&M documentation requirements are also provided in detail for each primary subcontractor or field. ASHRAE Guideline 4, *Preparation of Operation and Maintenance Documentation*, is highly recommended.

Chapter 7

CONSTRUCTION PHASE

During the Construction Phase of the project, the building systems (including architectural, structural, mechanical, electrical, and controls) are installed, undergo pre-functional performance tests, and are placed into operation. Once construction is completed, all the building systems should be operating as designed, both individually and collectively in the building as a whole, and are ready for functional performance testing. Figure 7-1 illustrates the activities associated with the three steps GSA performs during the Construction Phase. Please note that in the GSA process several activities associated with Buildout will be performed in the Acceptance Phase.

Figure 7-1
GSA Construction Phase Building Process



Commissioning activities in the Construction Phase are being performed in many agencies as part of their QA program. In the event that a successful QA program is in place, the Commissioning Authority is not meant to replace it, but rather to enhance the function and capabilities of the QA program. In many instances, an existing QA program or members of its staff will act as the Commissioning Authority. If an agency does not have a successful QA program, the building commissioning program will provide

the guidance for the development of a Commissioning Authority, or provide a means to contract with an outside firm.

The Commissioning Authority typically witnesses all pressure tests of the piping and duct systems and observes selected start-up testing, adjusting and balancing, and calibration activities. Per the Commissioning Plan and specifications, the Commissioning Authority also reviews the installation and observes the testing of the plumbing, life safety, control, electrical, and other building's systems.

An important element of the commissioning process during the Construction Phase is the training of the operating and maintenance personnel. These personnel should be available at the site during construction to observe the installation of the various systems, subsystems, and equipment and to learn about their function and/or operation in the commissioning process. The Commissioning Authority should coordinate this training with the owner.

Documentation

Submission of documentation describing the building's systems and building materials to be commissioned should be reviewed by the Commissioning Authority prior to construction. In addition to shop drawings, equipment submittals, TAB procedures, submittals to the Commissioning Authority should also include information to support the Commissioning Plan and commissioning documentation.

Submittals for the Commissioning Plan should include complete performance data for each piece of equipment including capacity, flow rates, velocity, pressure losses, horsepower, rpm, electrical data, and so forth. After review of building equipment submittals, the equipment operations and maintenance information (including part lists, installation instructions, and special tool needs) should be submitted in accordance with the equipment's specifications requirements.

Due to the importance of the control systems to the proper operation of the mechanical and electrical systems, control submittals should be carefully reviewed to ensure that they include all of the information required by the operations and maintenance staff to keep the controls system properly adjusted and calibrated. Submittal of control system information should include:

- Sequence of operation (narrative description of control system functions) cross-referenced to the control schematics and elementary ladder diagrams.
- Specifications sheets for each control component.
- A fully labeled control piping and wiring schematic, which shows point-to-point piping and wiring and includes all performance parameters such as set points, throttling ranges, actions, spans, proportional bands, and other control component adjustment or setting data. The locations of pneumatic test ports and electronic system terminal strips should also be indicated on the schematic drawings.
- Fully labeled elementary electrical ladder diagrams.

Pre-functional Testing, Start-Up and Initial Checkout

Prior to formal functional performance testing, systems must be installed, pre-start check lists completed, equipment started and initial operational checks made. Once the systems are certified ready by the installing and prime contractor, functional performance testing can begin.

Typically, after reviewing the equipment submittals and after reviewing specially requested installation, start-up and operations information, the Commissioning Authority develops prefunctional checklists and provides them to the contractors. Generic checklists are often used. These checklists contain tasks that many contractors already perform, but rarely document. In addition, the Commissioning Authority may provide input into documentation requirements for start-up.

The contractors then proceed with installation, filling in the checklists, and preparing the normal manufacturer field start-up sheets and other documentation requested by the Commissioning Authority. Systems are turned on and checked out by the contractors. The Commissioning Authority witnesses the start-up and initial checkout of selected systems, (large or critical), including the TAB work, and reviews the contractor-generated documentation of all systems. It is recommended that the Commissioning Authority spot-check the results of these checklists prior to functional testing.

Initial Controls Checkout

A proper controls system checkout is critical for proper building operation. Controls testing should be accomplished on each control device. Sensors should all be calibrated. Actuators should be checked

and adjusted for start and extent of travel. All relays and adapters should be checked should be checked for proper operation. Controllers should be checked for proper action. All system interlocks, interconnections, and safety devices should be checked for proper function.

All control devices should be adjusted and calibrated. All control settings should be verified by comparing actual input and output values to calibrated values. The documentation format for the controls checkout should be reviewed and approved by the Commissioning Authority before installation.

Testing, Adjusting, and Balancing

Before the testing, adjusting, and balancing (TAB) contractor can perform its tasks, the TAB agenda is approved and all pre-functional checklists should be completed, verifying start-up and sensor installation and calibration, and ensuring that the systems are ready for pre-functional and functional tests. TAB activities must be performed prior to any performance testing on any systems directly affected by TAB. This should include: electrical continuity testing, pressure testing, flushing, cleaning, start-up or activation of equipment and systems, and calibration and testing of automatic controls. Since each system test is unique to some degree, there is not one simple standard by which TAB measures can be applied to all systems and buildings. However, there are several different standards which may be applied including:

- *NEBB Procedural Standards for Testing, Adjusting and Balancing HVAC Systems*, 1983;
- Associated Air Balance Council National Standards, 1982;
- ASHRAE Standard 111-1988; and
- Other recognized standards that are approved by the design team.

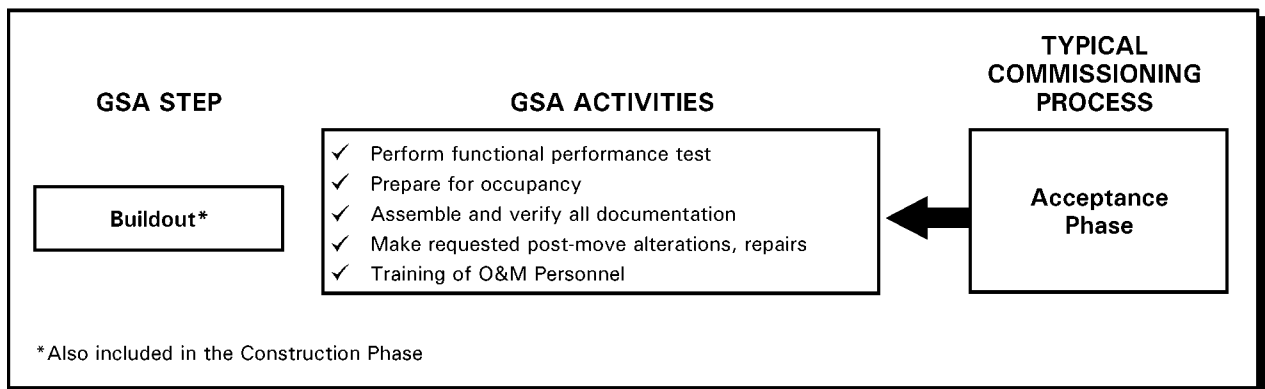
The entire testing and balancing process must be clearly documented. Recorded values must be clearly understood and reported in commonly used measurement values which are identified in the documentation and narrative of the testing method.

Chapter 8

ACCEPTANCE PHASE

Acceptance Phase procedures are crucial to determine if the building systems are operating in accordance with the design intent and contract documents. The Commissioning Authority typically supervises and directs the verification and functional performance tests performed during the Acceptance Phase. If deficiencies are identified during these tests, the Construction Manager is notified and action is taken to remedy the deficiencies. Follow-up performance tests are repeated after deficiencies are corrected. Figure 8-1 illustrates the activities which GSA routinely performs as part of a typical Acceptance Phase. As noted in Chapter 7, the Buildout step of the GSA process includes activities which are included in both the Construction Phase and the Acceptance Phase.

Figure 8-1
GSA Acceptance Phase Building Process



Functional Testing Procedure

The objective of the functional performance tests is to demonstrate that the systems and equipment are operating efficiently and according to design intent under a variety of conditions.

Although there are many ways to format a commissioning test plan, certain information should be clearly presented at the beginning of the plan to help guide the person responsible for performing the tests. This information is as follows:

- Equipment description
- Purpose of the test

- Required personnel, tools, and instruments needed to perform the tests
- Design information pertinent to the equipment or system being tested
- Detailed sequence of operation including any operating setpoints
- Scheduling requirements
- Special instructions or warnings
- Expected results, and
- Sampling strategies.

Test procedures forms vary in their detail, but should include space to record:

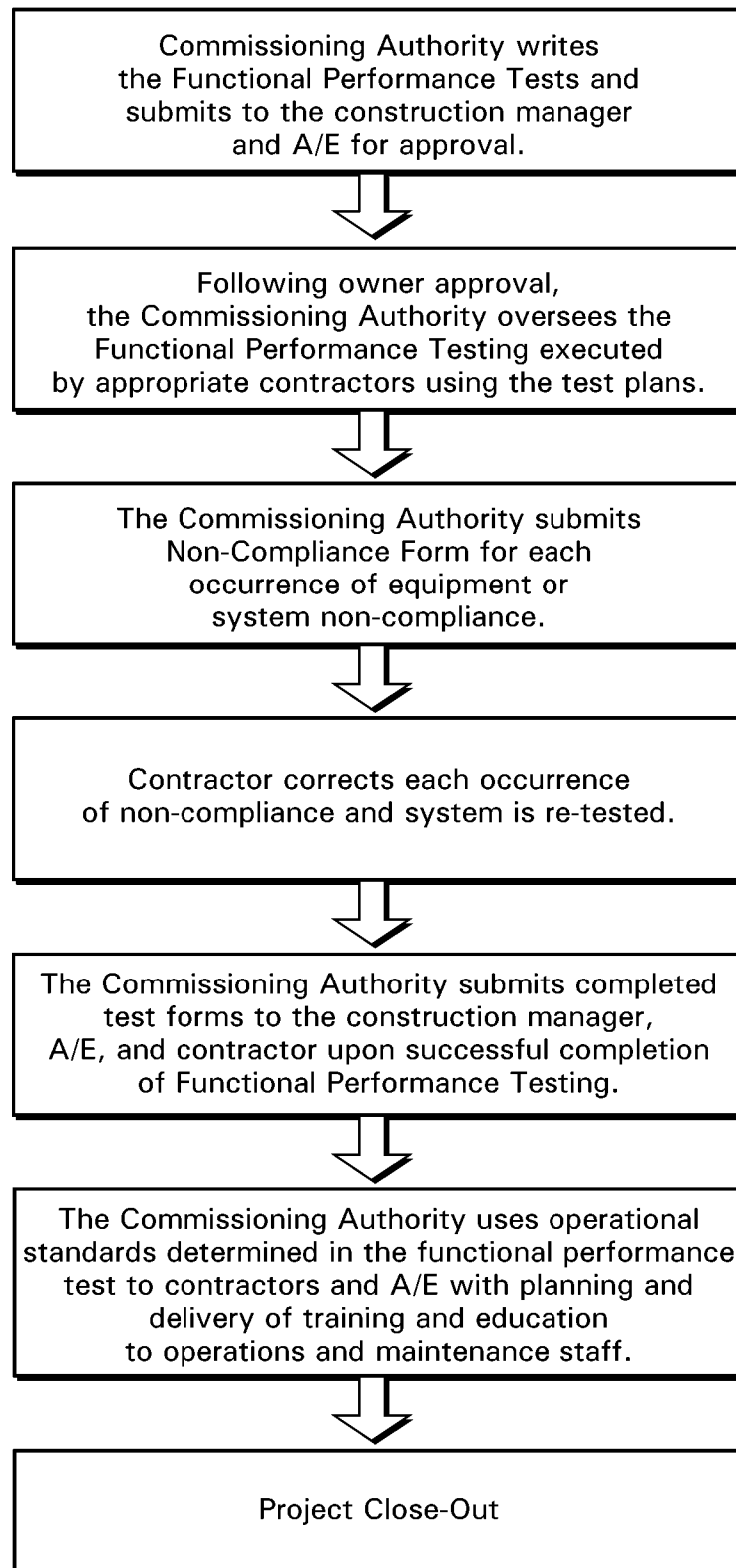
- Conditions of test;
- What was done to the system to cause a response, at each sequence;
- The expected response or acceptance criteria; and
- The actual response.

The functional performance testing process, as shown in Figure 8-2, should be accomplished for all mechanical, electrical and control equipment, subsystems, systems, and various system interfaces per the Commissioning Plan and specifications. The functional performance test contained in the approved building Commissioning Plan should be used to document the results of the tests.

Functional performance testing should progress in sequence, from individual equipment or components through subsystem operation to complete systems. As a result, the causes of many performance problems will be easier to locate and quicker to correct. The specific tests and the most efficient order of testing will vary widely depending on the type of systems, the number of systems, the sequence of construction, the relationship between building systems and specific tenant work, the degree of interaction between systems, the complexity of the controls sequence, the impact of system failures on health or safety, and other factors.

At the end of the process, every mode of building and system operation, all system equipment, system interfaces, and every item in the control sequence description will be proven operational under all normal operational modes including partial and full load, in all seasons, and under abnormal or emergency conditions.

Figure 8-2
Functional Performance Testing Process



Functional Performance Tests

Functional performance tests are performed to determine if the performance defined in the design intent documentation has been met. Each mechanical, electrical and controls system should be tested through all modes of system operation (for example, seasonal, occupied/unoccupied, warm-up/cool-down, and so forth, as applicable) including every individual interlock and conditional control logic, all control sequences, both full-and part-load conditions, emergency conditions, and simulation of all abnormal conditions for which there is a required system or controls response.

Temporary upsets of systems, such as distribution fault, control loss, setpoint change, equilibrium upset, and component failure, should be imposed at different operating loads to determine system stability and recovery time.

If a functional performance test cannot be accomplished for seasonal difficulties, lack of occupancy, or for other reasons, it should be noted in the commissioning documentation along with an indication of when the test will be scheduled. However, testing for out-of-season conditions can often be adequately completed by over-riding sensor values in the energy management and control system and witnessing the system's responses. If any test cannot be accomplished due to building structure or other building system deficiencies outside the scope of the mechanical, electrical, and controls systems work, these deficiencies should be resolved and corrected by the appropriate contractors before completion of the building commissioning process.

Every check or test for which acceptable performance was not achieved should be repeated after the necessary corrective measures have been completed. This retesting process should be repeated until acceptable performance is achieved. The retesting is performed as needed at the expense of the contractor(s) involved and is subject to "no claim for delay due to commissioning" clause in the solicitation and construction documents. The responsibility of the contractor and the importance of this clause should be clearly identified in the contracting agreement.

Testing may be accomplished in three ways: traditional manual testing (changing a set point, etc. and immediately observing a response), short-term monitoring using the energy management and control system trending capabilities, or monitoring using portable data-loggers. The monitoring requirements

should be detailed in the functional performance tests. The focus of monitoring and diagnostics for commissioning is on observing systems under different causal conditions (for example, cold weather, hot weather, occupancy extremes, emergency conditions, and so forth) in order to ascertain whether the system or piece of equipment is operating according to the design intent. This observation may occur over just one or two short periods of several days or up to several weeks. It is with this focus that a monitoring plan should be incorporated into the functional performance test procedures.

Integrated Systems Tests

When individual system functional performance has been verified, the integrated or coordinated responses between systems should be checked. The individual systems involved may be within the overall work of the building subsystem, for example, HVAC, or they may involve other systems, such as emergency systems for life safety. The integrated systems testing should be performed in the same manner as described above for building systems. Generally, the integrated systems testing can best be performed by monitoring the operation of multiple components and systems and graphically analyzing their concurrent operation.

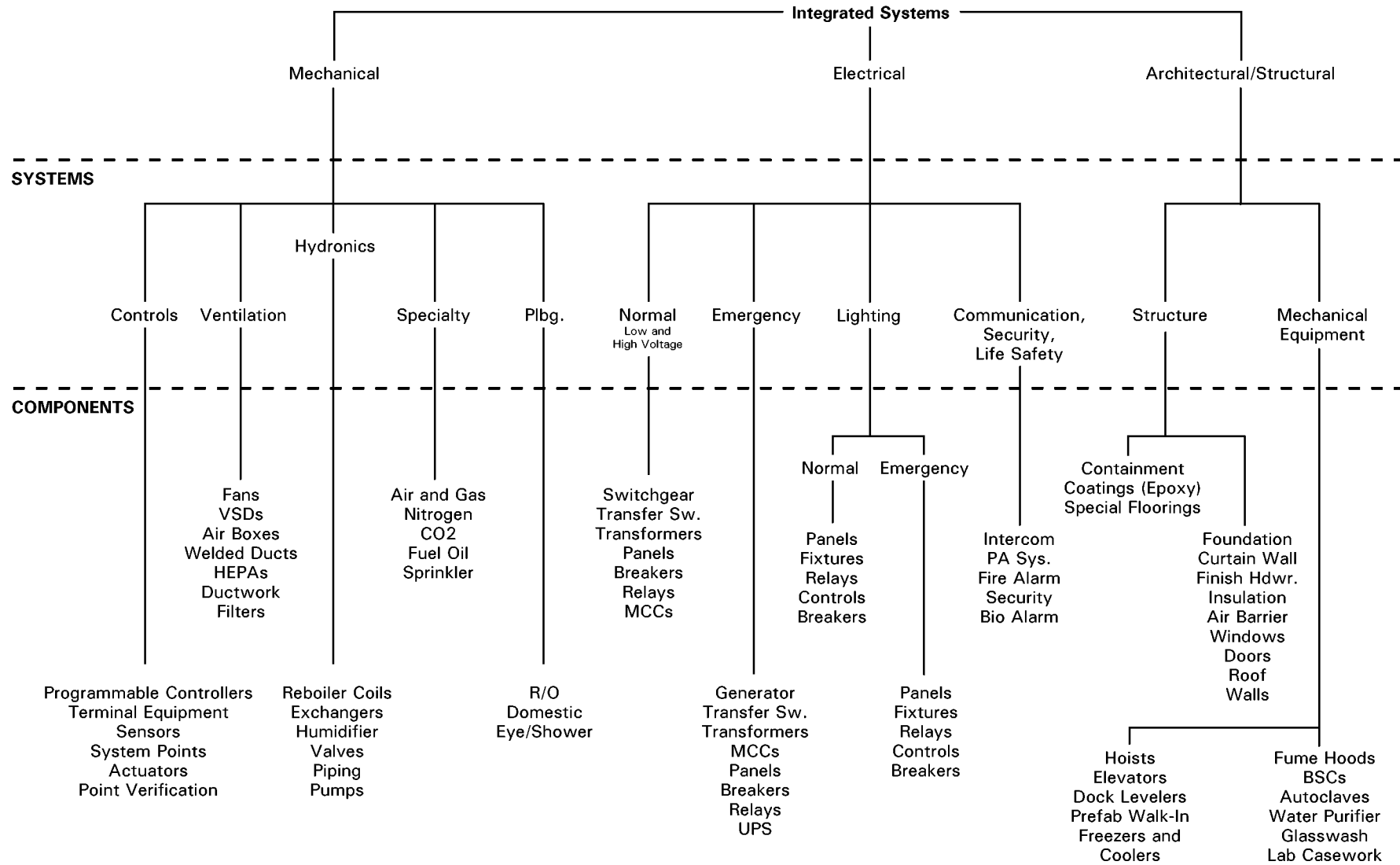
Figure 8-3 depicts some of the components and subsystems which need to function properly in order for an integrated system to operate according to the design intent.

Verification and Documentation

Verification is the process of concluding whether the contractors responsible for construction have met the obligation of their contracts. As each individual check or test is accomplished, the Commissioning Authority should observe and record the physical responses by the system and compare them to the specified sequences to verify the test results. The actual physical responses of system components are preferred. However, reliance on control signals or other indirect indicators is acceptable if the control signal and appropriate physical response has been verified through pre-functional tests.

Verification of the TAB report should be an integral part of functional performance testing. The Commissioning Authority should spot-check the TAB contractor's work, recording the results and comparing to the TAB report values.

Figure 8-3
Integrated Systems



A copy of the mechanical, electrical, and controls Commissioning Plan and functional performance test results should be included with each copy of the O&M manuals. These manuals, along with TAB reports, controls schematics, and any other documents required, should be submitted to the design team for review.

Some commissioning contracts task the Commissioning Authority with going beyond ensuring that the systems work according to contract documents. They require the Commissioning Authority to direct an effort to fine-tune and optimize system operation, comfort control, control parameters, sequences and energy efficiency.

The description of systems functions and/or operations contained in the commissioning and O&M documents should be updated to incorporate design or operational changes that occur prior to or during the Construction Phase, such as set points, schedules, sequences, etc. This information is combined as applicable, with the equipment maintenance data and equipment submittals, including performance data, to form one complete O&M manual for training, historical record, and subsequent use by the operations and maintenance staff.

Training of Operation and Maintenance Personnel

As part of the Acceptance Phase of the plan, for each piece of equipment or system, as specified in the contract documents, an O&M training plan is developed and released for comment to the responsible contractors, by the Commissioning Authority. Other scenarios have the contractors submitting training plans and having them approved by the Commissioning Authority. The goal of the training plan is to ensure that O&M staff are properly educated on how to maintain the new individual building systems as well as maintaining the building's system as a whole. The final training plan will specify the order and phasing of training, any materials and resources to be left with the trainees for later reference, and methods of measuring the success of the training. Videotaping and follow-up training should also be considered to provide a means for maintaining a qualified O&M staff as it changes over time.

The training and training documents should cover the following topics:

- Equipment and system descriptions
- Hands-on operation of the equipment and systems

- Equipment start-up, operation in normal and emergency modes, shutdown procedures, seasonal changeover, and manual/automatic control
- Requirements and schedules for routine maintenance on all necessary equipment
- Warranties and guarantees
- Common troubleshooting problems that might arise, with description of possible causes and corrective measures
- The operation and adjustment of dampers, valves and controls
- Emergency procedures
- Special tools needed and a recommended spare parts inventory
- Energy Management and Control System operation and programming
- Control sequences and strategies
- Relevant health and safety issues and concerns
- Energy management practices
- The maintenance management system
- When and how to recommission
- The information contained in the operating manuals and the location of all plans and manuals in the facility
- Design intent documents
- Relevant commissioning report documents
- Building walk-through
- Documentation in the final O&M manuals
- How to use the O&M manuals
- Acceptable tolerances for system adjustments in all operating modes
- Procedures for dealing with abnormal conditions and emergency situations for which there is a specified system response

O&M Manual Review

The Commissioning Authority receives the O&M manuals from the contractors near the end of construction and reviews them during the same period of time as the owner and A/E. However, only after functional testing is complete and final additions and corrections made, are the as-built sequences, set points and control drawings reviewed. The Commissioning Authority reviews the documents to ensure that they comply with the specifications, are complete, clear, and are well organized and accessible for use by the O&M staff.

Final Acceptance

When the requirements of the contract documents and Commissioning Plan have been completed and satisfactorily documented and any additional required documentation has been completed, submitted to the design professionals, and accepted, the Commissioning Authority should recommend final acceptance of the building and all building systems. The recommendation is issued subject to any outstanding issues or deficiencies that can not be resolved until a future date.

Final Commissioning Report

The commissioning report is intended to be the primary record document for commissioning for each specific system and the building as a whole. Information in the report should include the following:

Project name

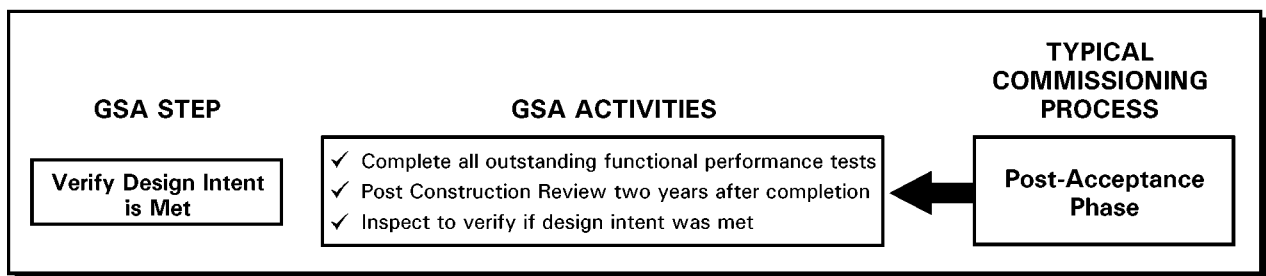
- Name, address, firm, and phone number of Commissioning Authority
- Description of the building
 - Size
 - Location
 - Use
 - Construction (envelope)
 - HVAC and other installed systems
- List and description of commissioning tasks
- Commissioning Plan
- Complete Documents
 - Completed design intent document
 - Completed pre-functional test checklists
 - Completed functional performance tests
 - All non-compliance forms
- Summary of commissioning findings
- Recommendations for system recommissioning
- Recommendations for monitoring the ongoing performance of the systems
- Recommendations for system improvements.

Chapter 9

POST-ACCEPTANCE PHASE

The Post-Acceptance Phase is an important step in ensuring the effective, ongoing functioning of a facility's architectural, structural and other building systems. As use and function of facilities change, the building systems need to be adapted to the changing requirements of occupancy and utilization. It is appropriate to maintain a history of the facility, recording changes and verifying the effect on the previously commissioned systems. Typical activities carried out by GSA in the Post-Acceptance Phase can be seen in Figure 9-1.

Figure 9-1
GSA Post-Acceptance Phase Process



As part of the Post-Acceptance Phase plan, many agencies will require an evaluation of the commissioned building after a set time period to assure that the design intent of the building is still being met. In the case of GSA, all commissioned buildings are scheduled to be retested after two years. In the event that the follow-up tests reveal that the original design intent is not being met, the Commissioning Plan will need to establish a recommended procedure to evaluate if a change in the mission and occupancy of the commissioned building has caused the variation.

Documentation

Before any facility modifications are undertaken their impact on building systems must be evaluated. As-built documents must be revised to reflect modifications made to any part of the facility or the building systems. Any change in usage, installed equipment, loads, or occupancy must be carefully monitored and documented along with commissioning reports.

As part of the Commissioning Plan for Post-Acceptance, several items need to be addressed by the O&M staff and should clearly be identified in the Commissioning Plan including:

- changes in the building usage, installed equipment and occupancy;
- documentation of any changes in set points, control sequences or overrides;
- equipment maintenance procedures;
- system servicing and maintenance documentation and problems;
- documentation analyzing the predicted and actual performance values; and
- documentation of comfort complaints.

If the variations are significant enough to warrant a recommissioning of the individual systems, or as a method of continued maintenance, the Commissioning Plan should recommend a system recommissioning schedule to ensure that actual system performance is maximized for the building's mission and occupants over the life-cycle of the buildings.

Maintenance

The building maintenance staff should regularly maintain and service the building systems and equipment as instructed by the contractors and equipment suppliers. The instructions in the maintenance manuals should be followed and accurate records of any work performed should be kept. The building systems should be retested periodically to measure the actual performance. The system functional performance test used in the Acceptance Phase should be used for retesting.

The operating and maintenance staff should develop and maintain a standard method of recording complaints received regarding the building systems and operations. Discrepancies between predicted performance and actual performance and /or an analysis of the complaints received may indicate a requirement to recommission a system or review the Commissioning Plan.

Chapter 10

REFERENCES AND ADDITIONAL RESOURCES

References

1. *Guideline for Commissioning of HVAC Systems, ASHRAE Guideline 1-1989*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1989
2. *ASHRAE Guideline 1-1989R*, ASHRAE, Atlanta, GA, March 1996
3. *The Building Commissioning Process*, ASHRAE Technical Data Bulletin Volume 9 Number 1, ASHRAE, Atlanta, GA, 1989
4. *Achieving a Quality Air-Conditioning System; A Commissioning Process*, Seminar Handbook, College of Engineering, University of Wisconsin, Madison, WI, 1994
5. *Prospectus Development Study Guide*, U.S. General Services Administration Public Buildings Service, Washington, DC, 1991
6. *Second National Conference on Building Commissioning*, Seminar Handbook, Portland Energy Conservation, Inc. (PECI), St. Petersburg, FL, 1994
7. *Procedural Standards for Buildings Systems Commissioning*, National Environmental Balancing Bureau, Rockville, MD, 1993
8. *Building Commissioning Guidelines*, Second Edition, PECO, Bonneville Power Administration, U.S. Department of Energy, Portland, OR, 1992
9. *Construction Management Guide*, U.S. General Services Administration Public Buildings Service, Washington, DC, 1990

10. Dunn, Wayne A. and John Whittaker, "Building Systems Commissioning and Total Quality Management," ASHRAE Journal, September 1994
11. Gupton, G. W. Jr., "Specifying Commissioning for Building HVAC Systems," ASHRAE Transactions, 1986
12. HVAC Systems Testing, Adjusting, and Balancing, Sheet Metal and Air-Conditioning Contractors National Association, Washington, DC
13. Lawson, C., "Commissioning and Indoor Air Quality," ASHRAE Journal, October 1989
14. Tseng, P., et al., "Commissioning and Construction Quality Control; A New Perspective on Facility Commissioning", ASHRAE Transactions, 1993

Sources for Commissioning Guidelines, Guide Specifications and Sample Functional Performance Tests

Source	Guide- lines	Guide Specs	Sample Tests
<i>Model Commissioning Plan and Guide Commissioning Specifications</i> , USDOE/PECI, 1997. NTIS: # DE 97004564 1-800-553-6847. PECI Web site: http://www.teleport.com/~peci	*Some D, c	*YES D, C	*YES
<i>The HVAC Commissioning Process</i> , ASHRAE Guideline 1-1996, 1996. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329.	Yes d, C	Some d, c	No
<i>Engineering and Design Systems Commissioning Procedures</i> , U.S. Army Corps of Engineers, 1995 (ER 1110-345-723). Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000.	Some d, c	Some d, c	No
<i>Commissioning Specifications</i> , C-2000 Program, Canada, 1995. C-2000 Program, Energy Mines & Resources, Energy Efficiency Division, 7th Floor, 580 Booth St., Ottawa, Ontario, Canada K1A 0E4.	No	*YES C	No
<i>Commissioning Guide Specification</i> , Facility Management Office, Univ.of Washington, 1993-6. http://weber.u.washington.edu/~fsesweb/	No	*YES C	Some

Source	Guide- lines	Guide Specs	Sample Tests
<i>Commissioning of HVAC Systems</i> , seminar/workshop training materials, Univ. of Wisconsin, Madison, 1994. 800-462-0876 or 608-262-2061	Some C	Some C	Some
<i>Laboratory HVAC Systems: Design, Validation and Commissioning</i> , ASHRAE collection of 11 papers, 1994. And,	Yes C		
<i>Commissioning Smoke Management Systems</i> , ASHRAE Guideline 5-1994. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329.			
<i>Standard HVAC Control Systems Commissioning and Quality Verification User Guide</i> , U.S. Army Const. Engineering Research Laboratories, 1994. Facilities Engineering Applications Program, U.S. Army Engineering and Housing Support Center, Ft. Belvoir, VA 22060-5516. FEAP-UG-GE-94/20.	No	No	Yes
<i>Contractor Quality Control and Commissioning Program—Guidelines and Specification</i> , Montgomery County Gov., State of Maryland, 1993. 301-217-6071.	*Yes c	*YES C	*Some
<i>Procedural Standards for Building Systems Commissioning</i> , National Environmental Balancing Bureau (NEBB), 1993. NEBB, 1385 Piccard Drive, Rockville, MD 20850.	Yes d, c	Some d, c	Some
<i>HVAC Systems Commissioning Manual</i> , Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), 1993. SMACNA, 4201 Lafayette Center Dr., Chantilly, VA 22021.	Yes c	Some c	Some
<i>Guide Specification for Military Construction—Commissioning of HVAC Systems</i> , Department of the Army, U.S. Army Corps of Engineers, January, 1993. Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000	No	*Some c	*YES
<i>Commissioning Guide</i> , Public Works Canada, Western Region, 1993. 403-497-3770.	Some d, c	Yes d, C	No
<i>Building Commissioning Guidelines</i> , Bonneville Power Administration/PECL, 1992. 503-230-7334.	YES d, C	Some c	Some
<i>The Building Commissioning Handbook</i> , The Association of Higher Education Facilities Officers (APPA), written by John Heinz and Rick Casault, 1996. APPA, 1643 Prince Street, Alexandria, VA 22314.	YES d, C	YES C	No

Source	Guide- lines	Guide Specs	Sample Tests
HVAC Functional Inspection and Testing Guide, U.S. Dept. of Commerce and the General Services Administration, 1992. NTIS: 800-553-6847.	No	No	YES
<i>Thermal Energy Storage (TES) Commissioning Guidelines</i> , California Institute for Energy Efficiency, San Diego State University, 1991. San Diego State University, Energy Engineering Institute, San Diego, CA 92182.	Yes C	No	Yes
<i>AABC Master Specification</i> , Associated Air Balance Council (Primarily for how the TAB fits into the commissioning process) AABC National Headquarters, 202-737-0202.	No	*Yes d, C	No

* Denotes that the documents are available on electronic disk.

D = for design phase, C = for construction phase. All CAPS denotes document is more comprehensive than lower case.

Web Sites Containing Commissioning Information

Oregon Office of Energy	http://www.cbs.state.or.us/external/ooe/cons/bldgcx.htm
Florida Design Initiative	http://fcf.state.fl.us/fdi/fdi_home.html
PECI	http://www.teleport.com/~peci
Texas A&M Energy Systems Lab	http://www-esl.tamu.edu
University of Washington	http://weber.u.washington.edu/~fsesweb/
Sunbelt Engineering	http://sunbeltengineering.com